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Future Short Range Ground-based Air Defence: System Drivers, Characteristics and Architectures

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Introduction

The widening political uncertainties and World instability of the last decade has led to the West moving away from maintaining armed forces largely to assure national survival. Now it looks towards maintenance of peace through promoting stability and countering regional aggression, and towards humanitarian operations including peace enforcement. This had led to a growing emphasis on expeditionary forces and away from the concept of "forces in place".

Short range ground-based air defence (GBAD) systems provide an essential defence capability for mobile expeditionary forces and provide the persistence which other air defence elements lack. Today's forces, however, face not just uncertainty, but capability gaps against the increasingly diverse air threat.

The end of the Cold War has overturned the assumed military imperatives. A threat now needs to be defined as a combination of two elements: Capability and Intent. Existence of one without the other is insufficient to establish a requirement for a capability, and both are subject to potentially rapid change. For GBAD, new attack technologies, including cruise missiles, unmanned air vehicles, attack helicopters and tactical air-to-surface weapons, plus the ability to obtain such technology off-the-shelf, may provide a first-class capability to any potential aggressor which has the political will to resource it. It is this potential level of Capability which sets the requirements for air defence. Meanwhile, assessment of intent based on traditional cold-war enmities and groupings has been largely overturned. The proliferation of weapon and sensor technologies, regional instabilities and the ease with which politically unstable countries may obtain near state-of-the-art equipment makes the definition of Intent volatile, changeable and difficult to assess.

Furthermore, both will alter with time, and a flexible methodology which can cope with change is needed for future systems analysis. The timeframe assumed for this paper is 2015 onwards. For any specific timeframe, however, assessment of the required capability for GBAD will be driven by the perceived air threat and the operational imperatives, the latter particularly including the need for interoperability of command and control in a multi-national joint environment.

Over the last decade, the UK's assessment of GBAD requirements for the future systems timeframe has been based upon a clean sheet approach, eschewing legacy systems and current assumptions. The studies in this timeframe have taken an assessment of the technological capabilities of future air vehicles together with an assessment of the potential operational environment that might condition their use. Initially, studies tended to concentrate upon actual warfighting scenarios as these are considered to be simultaneously the most stressing for defining the required capability, and of most relevance to operations in support of ground forces.

The increased operational emphasis on crisis reaction forces has, however, added a new dimension to the operational environment, implying a greater reliance on ad hoc groupings and committal to areas where little or no infrastructure may exist. The importance of information in wider peace support extends the range of operational conditions to be studied.

Aim

The aim of this paper is to describe how ground-based air defence concepts for the timeframe beyond 2015 may be synthesised from an assessment of the operational drivers and the technological factors, to produce robust modular concepts applicable to both warfighting and peace support regimes.

Paper presented at the RTO SCI Symposium on "System Concepts for Integrated Air Defense of Multinational Mobile Crisis Reaction Forces", held in Valencia, Spain, 22-24 May 2000, and published in RTO MP-063.

Scope

GBAD referred to by this paper is that of very short and short range air defence of ground-based assets in a crisis reaction context. It assumes that, although the scenarios will be multi-national, and operations will be conducted in a joint service environment, organic ground-based air defence of national forces will continue to be broadly a national responsibility. Although this paper is based on fundamentally UK studies, these have, however, taken place with considerable international liaison and participation in NATO fora, notably the RTO SCI Task Group on sensor fusion in SHORAD.

The paper does not specifically address the air defence (AD) of strategically- or politically-important assets which are not directly relevant to ground-based operations. Neither does it address ballistic missile defence, although system concepts derived by the methodology are routinely assessed for possible residual capability against such targets.

Methodology

The top-down study methodology is shown in Figure 1. The process follows the classic *thesis, synthesis, antithesis* approach whereby concepts are proposed either top-down or bottom up, synthesised in a system context and then tested in a range of operational scenarios to provide a basis for further concept development.

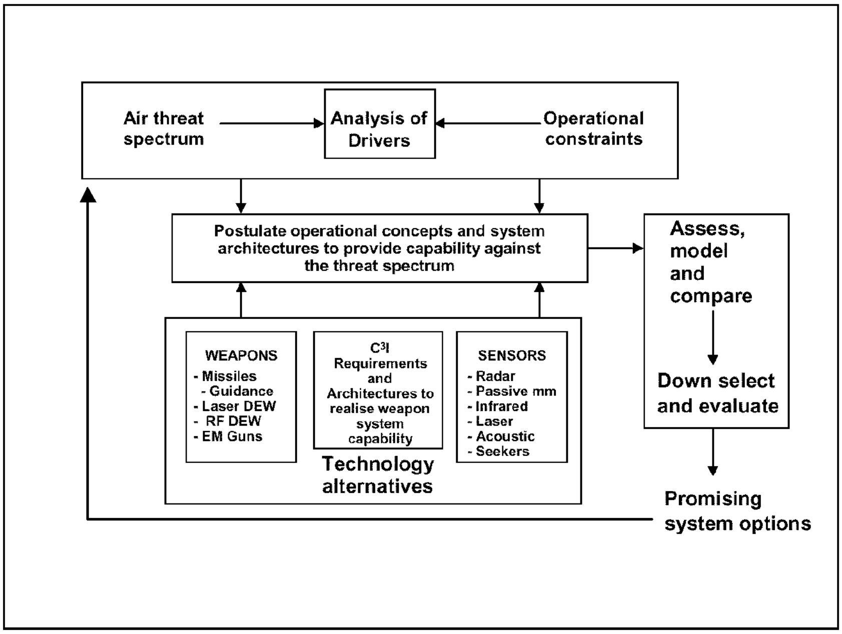

Figure 1: Overview of study methology

The first stage is to assess the developing threat and the operational conditions, which includes predictions of air threat technology advances and technology counters at the system and sub-system levels. The operational implications of this interaction are extrapolated into an assumed military doctrine relevant to the timeframe, that is developed through a combination of user experience and assessment against the principles of war. The UK perception tends to be that the Revolution in Military Affairs is more evolution than revolution, and although the rapidity of change provides great challenges, none of the new conditions are striking at the fundamental principles of war. In an uncertain and volatile future, these principles are held to provide the most robust framework for assessing potential system concepts.

Performance against each element of the derived threat array is assessed at a system level. No single threat element (eg., the ballistic missile) is allowed to dominate the concept development process, although the operational drivers (eg., non-line-of-sight helicopters) will carry more weight. The aim is for a flexible and balanced concept which has an assessed capability against the broad range of potential threats. This reflects

both the reality of uncertainty and the need for capability in a wide range of circumstances. This process is iterative and results in a gradually-refined concept which is relevant for the timeframe.

Results from technology watch and developments in the operational environment are brought into, and may drive the need for, subsequent iterations. Sensitivity analysis is carried out using a mixture of modelling and "soft" techniques, such as multi-criteria analysis, to refine the concepts as additional research data become available or are derived from systems studies.

The developing operational context

Analysis of the new spectrum of conflict indicates that forces must be trained and equipped for full warfighting in order to be in a position to discharge properly peace support functions. Similarly, it is generally accepted that materiel designed for "high intensity" operations, operated with extreme competence, is the best way to deter conflict at any level.

In a classic warfighting scenario, there are broadly two aspects on which to base an assessment: the diverse threat stream expected in the future; and the operational realities of the battlespace. The former includes specific target types, numbers and profiles, and may include multiple simultaneous threats. The latter involves the need to be able to move, survive and fight on the battlefield without compromising operational security.

In a peace support context short of warfighting, additional imperatives need to be taken into account. The manoeuvrist approach espoused by "The British Military Doctrine" already puts an emphasis on the OODA (Observation, Orientation, Decision, Action) loop, and the use and deployment of information to get inside the decision loop of the enemy, so as to surprise him, or to challenge him with conditions to which he is unable to produce a timely response. The development of information warfare at the geo-strategic level, and its application as command and control warfare at the operational level, will place additional demands upon the supply, interpretation and exploitation of information.

It seems inevitable, therefore, that in order to keep inside the decision loop of the enemy, be this in terms of conventional or asymmetric warfare, there will need to be an increasing emphasis on information-gathering sensor-based systems. The need for increased situational awareness is assessed to make weapons subsidiary in importance to the surveillance and sensor function.

An illustration of the assumed process is given at Figure 2, which suggests that sensor needs will dominate as firepower-based system considerations decline.

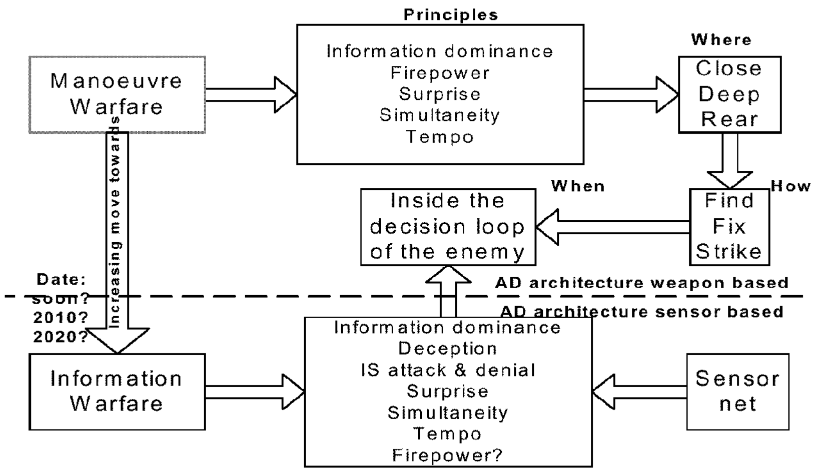

Figure 2: Assumed doctrine development

Information itself may supplant some aspects of firepower, although an effective kill mechanism will remain an essential part of the overall system. Sensors are likely to become more generic and less tied to AD weapon platforms. Political control will be an increasingly-important factor in all military operational planning, and

there is already an emphasis on the avoidance of casualties, particularly of civilians and neutrals. Commitment of forces is likely to involve a stated or assumed moral dimension. In particular the avoidance of civilian and neutral casualties will outweigh any operational risks incurred by following this policy, at least until action is joined and the first casualties taken. This trend is already apparent in NATO rules of engagement which suggest that no target should be engaged unless it has been observed committing a hostile act or has been declared hostile.

This projected future is illustrated by the influence diagram at Figure 3. Lines indicate influences on actions, with plus signs indicating a positive relationship, and minus signs the inverse.

The evaluation represented here suggests that all influences in a non-warfighting situation will tend to exacerbate the current requirement for severely-restrictive weapon controls. In the future, this may manifest itself as restrictively high identification thresholds from the identification data fusion process.

Only if enemy action occurs, and casualties are suffered, will the moral imperatives diminish and the need for more effective GBAD act as a counterweight to the restrictions on operations. The need to maintain control in the battlespace, and the continuing political imperatives to avoid friendly and neutral casualties will increase the importance of obtaining air target identification information to assist this process. This additional data may be used to segment the target set so that priorities and comparative risk assessment can allow relaxation in weapon control status, or in identification threshold levels. This will allow the increasing proportion of the target set which is unmanned to be engaged without increasing the fratricide risk for manned platforms.

The operational environment

It is assumed that the aim of future ground-based air defence will remain "to prevent interference from the air with the conduct of ground operations while contributing to the counter-air battle". For ship-based air defence, the aim is to prevent interference with naval operations, where the wartime coalition littoral operational environment presents the most challenging requirement to be satisfied. Changes in the World Order, emphasis on manoeuvre warfare, and the potentially wide threat spectrum require development of a framework which goes beyond the linear battlefield conditions which were in place during the Cold War.

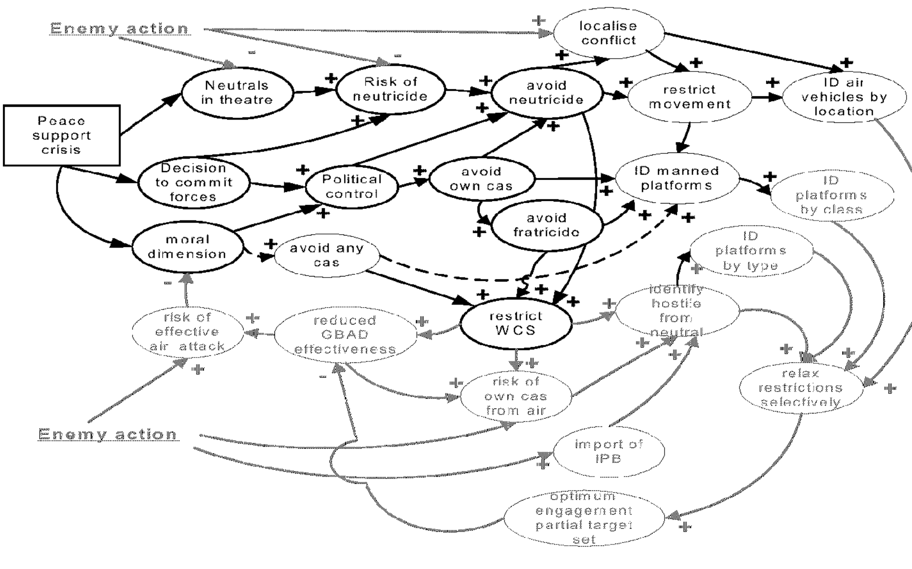

Figure 3: Some influences on the ATI requirement

Warfighting scenarios tend to be relatively well understood, but a crisis reaction scenario implies an operation of an expeditionary nature with a number of potential primary intentions, amongst which might be to: deter, prevent, enforce or restore. Peace support operations may involve peacekeeping, peace enforcement or peace making or a combination of all three. Similarly, the prime posture of engaged forces may vary from policing

through coercion to full warfighting. Information requirements may vary from the need to monitor potential aggressors, through identifying targets for selective engagement, to providing "evidence" of transgression. Evidence is also likely to be required to justify the need for force to international investigative bodies after any resort to armed action, even in self-defence.

A large number of major factors are at work in any battlefield AD situation. The geometry of the potential battlefield will depend upon the scenario, plus the force levels committed, and the capabilities and intentions of the hostile forces. This set of basics, together with the potential number and combination of air targets, plus the number and scope of potentially vulnerable assets needing to be defended on differing parts of this battlefield, make a set of variables which is too large to be modelled and assessed.

The "Zone concept" – a focusing framework

However, some of these combinations may be mutually exclusive, or at best highly unlikely. To help maintain a balanced view of all the factors, a focusing framework has been developed with the main factors illustrated in Figure 4. The resultant "Zone concept" is based upon the principle that the air threat to ground-based forces will tend to be a function of the nature of the ground-based asset itself, which will, *inter alia*, depend on its function and importance, its location on the battlefield, the time or stage of the battle, and perhaps most importantly, the ease of targeting - which includes consideration of its "visibility" to electronic and visual systems, its mobility and the "five S's"s (size, shadow, shape, shine, silhouette). Other factors include the value and level of protection of the target. The former will depend upon its inherent battlewinning performance, or political sensitivity, relative scarcity and the time/stage of the battle, whereas the latter will tend to depend on its mobility, "hardness", size/layout and posture, location on the battlefield, terrain, and signature. Finally, the vulnerability, survivability, numbers, technological sophistication, level of training, culture etc., etc., of the attacker must be taken into account.

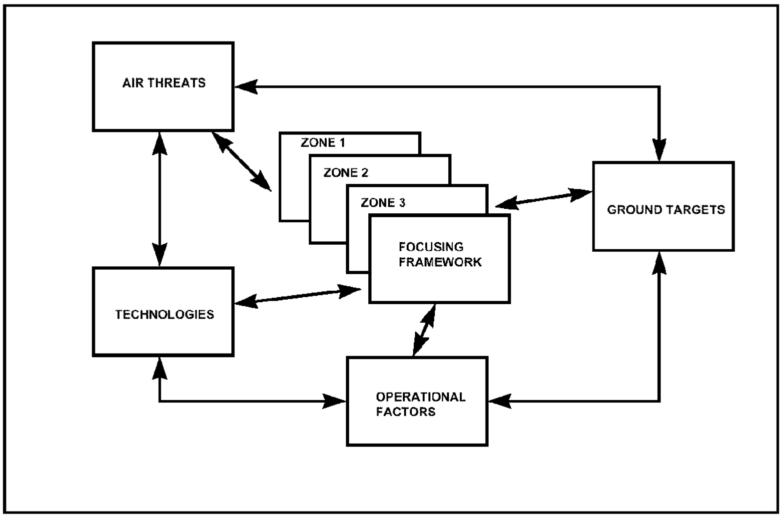

Figure 4: Zone concept as a focusing framework

The vulnerability relationship of the defended asset itself may be complex, especially for manoeuvre elements, as illustrated in Table 1. This shows the inherent vulnerability of combat elements to attack, the least vulnerable being on the right. Although for completeness the defended asset characteristics shown in Table 1 are based upon a conventional armoured formation, and implicitly at divisional level or above, they could also apply at lower levels of force commitment and of equipment capability. A broad summary of the most likely targets to be seen over the battlefield is given at Table 2, which attempts to "Zone" categories of hostile air targets by broadly relating these to targets to be defended by friendly AD.

Main Factor	Element	Greater <	<	<	< Less
Ease of targeting	Location	Mapped	Static	Semi-static	Mobile
	Movement	convoy	x-country	stopped	deployed
	Posture	concentrated	tight	dispersed	widely dispersed
	Physical	big/hot	mid-size/cool		small/cold
	Camouflage	scrimmed	draped	visual	full/thermal
	EMCON	4	3	2	1
	Visibility	line of sight	occulting/obscured		non line of sight
	Contact	static FLOT	fluid	confused	melée
Protection	Armour	soft	semi-hard	hard	defensive aids
	Digging	in open	under cover	dug in	full o/h protection
	AD	none	AAAD	CAD	fully layered AD

Table 1: Combat asset vulnerability

Zone	Grouping by air target type	Air target density	Characteristics of defended asset
1 **Combat elements**	FW - CAS Attack helicopter Hovering helicopter with SOW UAV (tactical) TASM (TGSM)	✈ ✈ ✈	Mobile/manoeuvring Protected – unprotected Dispersed Up-to-minute location fix needed Some relatively small static targets Tactically valuable
2 **Combat support elements**	Subsonic cruise missile TASM UAV (tactical & operational) FW - BAI & SEAD (ARM) RW/tpt aircraft (désant)	✈ ✈	Relatively immobile Static or slow-moving Medium size Location by map fix or surveillance Operationally valuable
3 **Politico-strategic assets**	Super/subsonic cruse missile, TASM Stealth aircraft FW - AI & SEAD UAV (strategic, HALE)	✈	Static Medium/large size Location known Strategically or politically valuable

Table 2: Target and asset distribution

The degree to which an enemy might possess capability in all these threat categories would depend on the individual scenario. The descriptor "Zone concept" does not imply a linear battlefield, but recognises the fact that combat assets tend to group together, and strategic level assets tend to be located relatively far from the combat zone, although this is by no means always the case, especially in peace support operations where "enclaves" may be a major characteristic.

Analysis of asset deployment over time has suggested that the broad groupings indicated in Table 2 overleaf will remain broadly valid over a wide range of scenarios. With minor changes, these groupings have been the basis for all future systems studies.

The design drivers for AD weapon systems are likely to change largely as a result of the characteristics of the targets to be defended and the factors already stated. The characteristics of an AD system for defence of manoeuvre units in contact will be notably different from that for defence of an operational level asset such as a Sea or Air Port of Disembarkation (SPOD, APOD).

In this focussing framework it is the characteristics of the *assets* to be defended that define the requirements for AD, and there are likely to be considerable overlaps between Zones. A summary of the Zone Concept is provided by the illustration at Figure 5. Zone 3, which is the vital area defence of assets of strategic or political importance, where the decision to defend is not made on military grounds, and where the consequences of failure are of greatest significance, is not shown. The Zone 3 threat is only included in Table 2 for completeness as the strategic/political threat, as already highlighted, is beyond the scope of organic short-range GBAD.

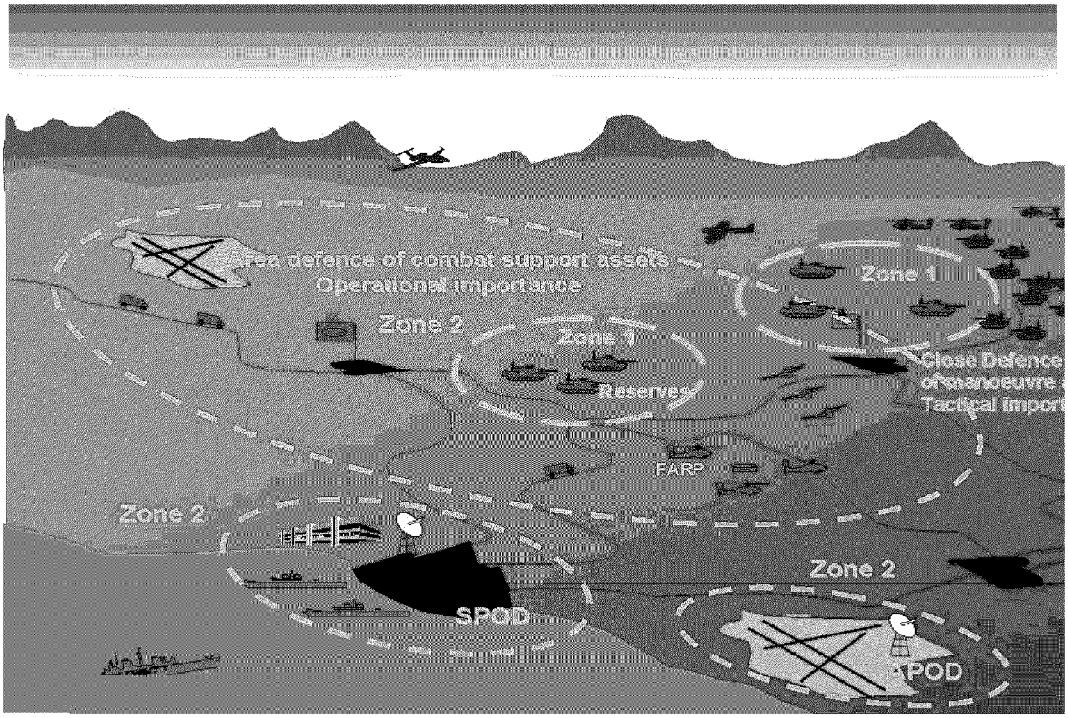

Figure 5: Zone concept

The characteristics of the derived threat are critical drivers and technical analysis of likely developments indicate a complex pattern. Although it is reasonable to group air threat platforms into generic representative classes for analysis, the factors which affect their characteristics all need to be taken into account. Some of the factors applicable to fixed wing aircraft are illustrated in Figure 6, which indicates a number of possible trends. Although the effect of each factor will be largely scenario-dependent and the shape of each factor may be debatable - for example, whether the application of low-observable technology is likely to follow a stepped upgrade pattern as indicated – the overall trends can normally be agreed.

Analysis of the air targets considered to be a priority in Zones 1 and 2 suggests that these are likely to change over time, as shown in the summary in Table 3, where the targets are shown in order of assumed importance for the mid and far timescales. The table indicates the growing threat from the attack helicopter (AH) and small target set, and the relative decline in the importance of the fixed wing aircraft (FW) target. Such analysis also confirms the dangers of an asymmetric degradation of operational capability if the fratricide danger to manned aircraft is allowed to drive overly restrictive weapon control status.

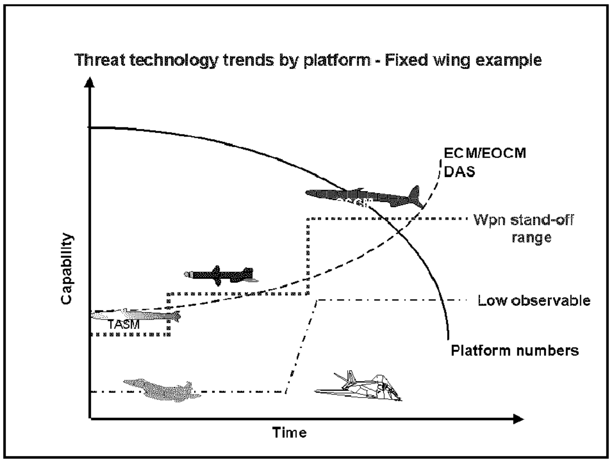

Figure 6: Illustrative threat factors for a single platform type

	Mid term ~2010	Far term ~ 2020 onwards
Zone 1	AH Tactical UAV FW TASM CM	TASM AH Battlefield UAV CM (FW)
Zone 2	FW CM Tactical level UAV SSCM Operational level UAV	TASM UCAV SSCM CM Operational level UAV

Table 3: Target priorities in Zones 1 & 2 over time

Emergent AD concept drivers

It is mainly operational issues which delineate the Zone 1 requirements from those of Zone 2, which are broadly threat driven. The Zone 1 AD element has to be able to provide air defence for highly mobile operations on a dispersed battlefield, whilst surviving and maintaining operational security. As the all-weather and through-cloud threat increases this will create a requirement for active systems that will compromise security and survivability. The greatest threat in the latter context is artillery, so active systems must have low probability of intercept and their concept of operations must be difficult to template. A crossing target capability against the Zone 1 threat stream is necessary to free the AD system concept from the need to collocate with defended assets and to enhance security. The advantages of being able to separate the sensor function and weapon functions so as to be able to optimise each without compromising the other, and to exploit the geometry of the battlefield to allow more survivable deployments, becomes very attractive. Such distributed system concepts also allow more radical approaches to the support of moving assets than allowed by concepts which depend on weapon systems collocated with sensors. The greatest technical threat in this Zone is the non-line-of-sight (NLOS) helicopter. The greatest system drivers are this NLOS requirement and the short timelines associated with late-unmasking targets, coupled with the need to be able to satisfy the engagement criteria without the restrictions implied by a requirement for the visual recognition of targets.

Zone 2 is characterised by the most technologically sophisticated and diverse threat with the main drivers being the stealthy small target and the steeply-diving TASM, coupled with a need to be able to match the arrival rate of a multiple and multi-directional threat. Situational awareness, with its implicit benefits for air

target identification, and the maintenance of an efficient sensor net in the presence of the most severe countermeasures, are also fundamental to timely and effective engagement.

An all-pervasive driver which is particularly important in a crisis reaction force context, is the need for adequate air target information which will allow effective engagement of the more stressing target set whilst holding fratricide risk, particularly of manned platforms, to an acceptably low level.

An assessment of the most important AD drivers derived from this process is shown in Table 4.

Zone 1 **Defence of manoeuvre forces**	**Zone 2** **Defence of support elements and formations not in contact**
• Mobile operations • Protection • Operational security • NLOS helicopters launching SOW • Increasing numbers of small targets (especially UAV) • Increasing above cloud threat • Need to be able to engage beyond visual identification range • Crossing target coverage • Robustness against self-protection measures	• Low-observable cruise missiles • High-speed steep diving TASM • System survivability • Proliferation of low-cost missiles. • Increasingly accurate all-weather threat. • Supersonic cruise missiles for stand-off attack of fixed assets • Maintenance of Situational awareness • Resistance to C2W

Table 4: Emergent AD concept drivers

Technology alternatives and architectures

The areas within which it is necessary to consider technology alternatives to populate system and sub-system architecture proposals, consist of weapons, sensors and C^3I. Within these areas there will be other considerations such as multi-function possibilities and fusion of information at various levels. The linkage of technology alternatives with the discussion of emergent AD concept drivers is through a general statement of requirements as exemplified in Table 5. The broad requirements have been stated without reference to Zone and there will be detailed trade-offs between system requirements, capabilities and implementation when the operational aspects of Zones are considered. The driving aim, however, is to keep in mind the potential for modularity at the architecture, technology and functional levels to achieve a robust AD system to meet the operational requirements identified through the Zone concept focusing framework.

Required broad AD system characteristics
• All-weather capability • Good performance against physically small and low-observable targets • Good performance against low attitude targets • Good performance against fast crossing targets • Capability against NLOS helicopters • Maintenance of performance in a countermeasures environment • Provision of simultaneous channels of fire from a single equipment • Minimum vulnerability to Defence Suppression and asset fingerprinting • Capability to operate with C3I integration and autonomously • Modularity

Table 5: Required broad AD system characteristics

Whereas many features of Table 5 can be identified as germane to current AD missile systems, results from Operational Analysis and lethality studies have shown that for a future AD system:

- the forecast threat will require a significant increase in lethality compared to current systems;
- a capability against air-launched missiles will be essential;
- engagement ranges, against agile and fast crossing targets, greater than 7-8 km are highly desirable to minimise the regime where neither threat launch platform nor threat munitions can be engaged. It should be noted that the most up to date, authoritative reference on engagement range requirements is extant in the latest NATO Staff Requirement for VSHORADS/SHORADS ;
- the most demanding target detection requirements are set by those targets which operate at very low altitude, by missiles with high, terminal dive angles, and by the very fast LO missile target;
- a capability to provide multiple, simultaneous fire channels from a single equipment will greatly improve resistance to saturation attack from stand-off missiles;
- a NLOS capability will be essential for the defeat of attack helicopters, and improved system effectiveness against both missile and fixed wing threats;
- the ability to site sensors and launchers remotely from each other can enhance system performance, particularly against small cross section targets at very low altitude, and confer other benefits of operational security, survivability and flexibility.

Weapon level architecture options

Initial weapon studies examined potential kill mechanisms based on conventional missiles and novel weapons exploiting Directed Energy Technology (DET) using lasers or RF techniques. It was concluded, and this remains the assessment, that, for the timeframe of interest, novel weapon techniques would be very unlikely to supplant missile-based weapons as the prime kill mechanism. On the other hand, a number of laser-based concepts were assessed as possible and attractive in the context of threat platform sensor dazzle and damage capability. Such soft kill concepts could form the basis of a complementary, adjunct, sub-system in a predominantly missile-based AD system.

Early work on future AD missile-based technologies and concepts focused on a thrust towards physically small missiles. This implies a small warhead, high agility matched to an increasingly rich unmanned target set, but demands small miss distances for high terminal lethality. The thrust was predicated on:

- factors imposed by the User to minimise equipment weight and size;
- threat factors of diversity and "smartness" encompassing increased agility, speed and co-ordination of attack, longer stand-off ranges with an ultimate need to engage the launched ordnance plus intensive use of ECM/EOCM.

Work addressed, and continues to address, the combination of sub-system technologies which could lead to reduced miss distance, the practical limits for miss distance reduction against small manoeuvring targets, and the implications for overall missile design. The crux of the philosophy is linked to achieving a sub-metre miss distance with a small missile and warhead, and this leads to guidance methods based on terminal homing.

The use of terminal homing guidance also potentially confers a number of major system benefits in relation to the discussion on operational factors. These include:

- decoupling of ground sensors from launchers to achieve flexible, distributed sensor and weapon architectures. Important operational benefits are reduced fingerprinting of defended assets, reduction of deployment constraints on engagement coverage, and tolerance to battle damage;
- inherent potential for multi-target engagement capability;
- inherent potential for good crossing cover at high target speeds;
- inherent NLOS helicopter engagement potential.

A full assessment of the spectrum of missile guidance techniques and architectures is beyond the scope of the paper; however, in the context of the indicated focus on terminal homing and seeker options, some limited comparison of options against perceived requirements can be made. Such a comparison is shown in Table 6. Corresponding composite, weapon level examples of architectures are illustrated in Figures 6 and 7. These are not exhaustive, but do illustrate possibilities for sensor options to support weapon delivery from surveillance to kill assessment.

Guidance	**Surveillance and tracking sensors**		**Principal system limitations or vulnerability**
	Active surveillance & tracking	Passive surveillance & tracking	
Command to Offset Line of Sight (COLOS) to intercept	Phased array radar, or, LPI surveillance radar + Differential radar tracker	IRST / passive millimetric alerting Laser rangefinder	Line of sight engagements only Expensive radar requirements Range dependency of miss distance Target illumination throughout flyout
Radar Information Field (RIF) guidance to intercept or for mid course with terminal seeker	LPI surveillance radar RIF projector / tracking radar	IRST / passive millimetric alerting Laser rangefinder	Line of sight engagements only Limited crossing target capability Target illumination throughout flyout
Semi-active RF or RF/IIR seeker (with or without command mid course fly out)	LPI surveillance radar RF illuminator / tracker or, Phased array radar	IRST / passive millimetric alerting Laser rangefinder	Line of sight engagements unless airborne illuminator used Target illumination throughout flyout if semi-active all the way Expensive radar requirements
Laser Information Field (LIF) guidance	LPI radar	IRST / passive millimetric alerting Laser rangefinder / LIF projector	Weather limitation on engagement range Line of sight engagements only Limited crossing target capability
PN mid course command guidance and multi-spectral seeker	LPI surveillance radar (track while scan), or, low cost phased array radar	IRST / passive millimetric alerting Laser rangefinder	Necessity to contain missile costs

Table 6: Some candidate AD weapon system architectures and comparative assessment of key limitations

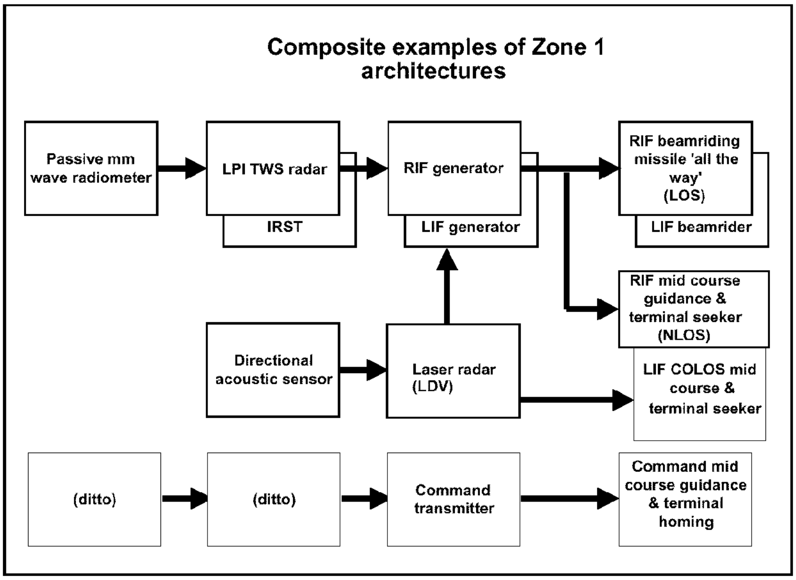

Figure 6: Illustrative Zone 1 options

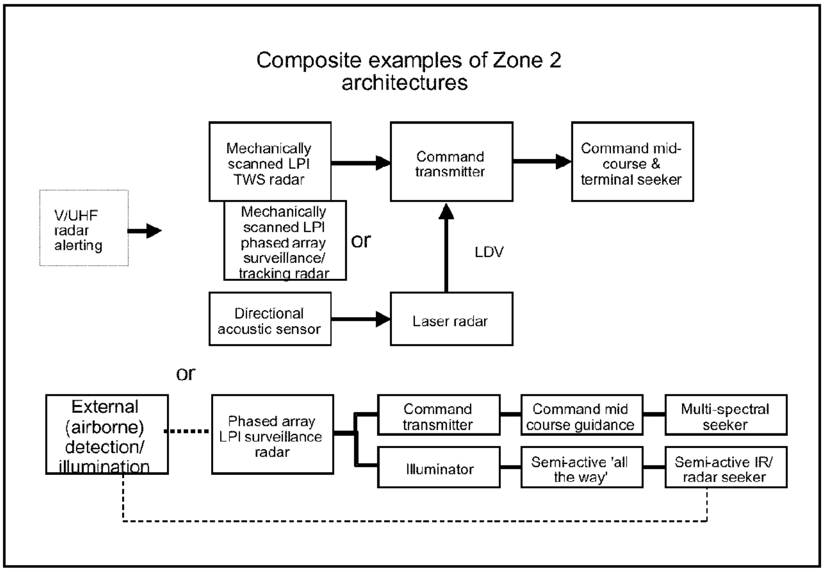

Figure 7: Illustrative Zone 2 options

Surveillance sensors

The illustrative architecture diagrams reference (non-exhaustively) a number of sensor technology options spanning radar in various wavebands, infrared search and track (IRST), passive millimetric radiometry, laser and acoustic. UK-specific studies and joint, collaborative studies within NATO RTO SCI032 have addressed surveillance sensor technologies to support future missile systems. SCI032 derived a Technology Matrix (TM), which illustrates qualitatively the performance attributes of surveillance sensor techniques across the electromagnetic spectrum. This is shown in Table 7 overleaf which consists of columns which address salient attributes of desired sensor performance characteristics, and rows which address generic methods of target discrimination (against clutter, ECM, etc.). The TM entities refer to specific technologies which exploit the physical means of target discrimination. A combination of objective and subjective analyses led to grading of the specific technologies in terms of perceived credibility and performance within the future timeframe. It is to be noted that Table 7 introduces air target recognition and identification characteristics of technology solutions.

Desired Sensor Performance Characteristics

Target discriminants	SHORAD Rdetect Day/Night	SHORAD Rdetect All Weather	SHORAD Rdetect All Climates	Good Accuracy, Resolution	Covert	Recognition and identification	Multiple target capability (system)	NLOS partially masked (helo)	NLOS fully masked	Robustness against Counter measures
Reflection Coef (Radar)	D E	D **E**	D *E*	(i) *D(ii) D(iii)* E*D(i)*	**D(ii) D(iii)** E	*D E*	D(i) D(ii) *D(iii)* E	*D E*	**D(iii)**	*D E*
Temp (emissive)	A B		*A B*	A B	A B	*A B*	A **B**	*A B*		A B
Temp (reflective)	C **H**	C	C *H*	C H	C H	**C** H	C **H**	*C H*		*C H*
Polarization	B D	D	B D	D(i) *D(ii) D(iii)* B	**D(i) D(ii) D(iii)**	B *D*	B D	BD	**D(iii)**	B D
Effluent (chemical)	E(iii) B		E(iii) B	E(iii) B	E(iii) B	E(iii) B	E(iii) B	E(iii) B		E(iii) B
Turbulence (Helo)	*E(iii)*		**E(iii)**	E(iii)	E(iii)	**E(iii)**	*E(iii)*	*E(iii)* **B**	*E(iii)* **B**	E(iii)
Sound	G *E(iv)*	**G**	G *E(iv)*	**G** E(iv)	G E(iv)	G *E(iv)*	**G E(iv)**	G E(iv)	G E(iv)	G
Emitter (Intermittent)	*F*	*F*	*F*	*F*	F	***F***	*F*	*F*	*F*	F
Emitter (Cooperative)	I	I	I	*I*	I	I	I	*I*		**I(i)** I(ii)

Table 7: Sensor technology matrix

Symbol	Technology
A	IRST(Infrared Search and Track) i – Hyperspectral ii – Broadband
B	IIR (Imaging Infrared)
C	PMMW (Passive Millimetre Wave)
D	RADAR i– mm ii– cm iii – m and lower
E	LASER i – designator ii – rangefinder iii – Laser Doppler Velocimetry (LDV) iv – Laser microphone v – Laser vibrometry
F	ESM
G	Acoustic
H	Visual
I	IFF i – Mk XII (STANAG 4193) ii – SIFF (Successor IFF, STANAG 4162)

Table 8: Legend for Table 7

The assessments in this respect refer to the potential for Non Co-operative Target Recognition (NCTR) with radar, electro-optic, acoustic technologies and with co-operative techniques such as ESM and IFF systems.

Table 8 provides the legend for the TM. It should be noted that the symbol convention is on a (relative) 3-point scale of projected credibility/performance, running from **bold** (worst case) through *italic* to <u>underlined</u> (best case).

The TM shows a wide spread in projected capabilities and limitations of individual sensor technologies. It emphasises:

- the contrast between the use of active and passive technologies against the criteria of realistic range performance in poor weather, covertness, and countermeasures resistance, and the difficulty of finding a robust single sensor solution without compromise to essential performance characteristics;
- the difficulty of finding a robust single sensor solution to the ground-based detection of NLOS helicopters, especially when fully masked by terrain;
- the continuing problems in finding a robust solution to air target recognition and identification;
- the need to research new technologies which may have high pay-off in the areas of counter-stealth, survivability, NLOS target detection. Current indications are that such technologies, embracing new radar frequency bands, atmospheric turbulence, high resolution techniques for NCTR, etc., will be best used in concert with other sensors.

The fundamental message is the need to consider sensor fusion techniques in the context of synergy to close performance gaps without significant operational penalties. This constituted the remit of SCI032, which has completed the largely qualitative Phase 1 assessment and is moving towards quantitative evaluation of promising options in the current Phase 2, under the aegis of SCI069. During Phase 1, it was necessary to postulate a "reference AD system" which could provide good potential capability against the wide threat spectrum, and which constitutes the baseline from which to examine and evaluate enhancements through sensor fusion. The derivation of the reference AD system followed a similar methodology to that undertaken by specific UK studies, *q.v.*, Figure 1, and, in general, reached similar initial conclusions.

AD system architecture building blocks

Figure 8 shows a schematic of the reference AD system which emerged from the SCI032 work, and which has also been derived in UK-specific studies for Zone 2 application. The reference system should be viewed as an autonomous building block with which to explore modular enhancements and alternatives, including fusion schemes to improve air picture spatial and identification integrity both in a local (collocated) and a wider, more global (fully distributed) context.

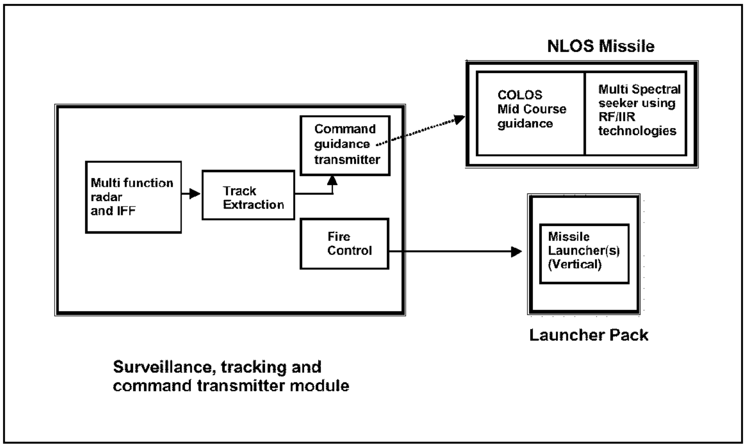

Figure 8: Reference (autonomous) system

The reference building block incorporates a terminal homing missile (hence an NLOS capability) using a multi-spectral RF/IIR seeker whose mid course guidance is provided through a command transmitter using track data from a multi-function radar (MFR).

The latter provides initial surveillance, with integrated IFF and a potential capability for non co-operative target recognition through high range resolution profiling. It is also possible to consider an integral ESM interferometer sensor to support establishing emitter identification when available. A collocated or remote weapon pack with vertical launch of missiles completes the system. Essentially, the reference system provides an intrinsically powerful autonomous kill capability through use of the dual mode seeker employing complementary spectral band attributes, including within-seeker fusion when appropriate.

Integrated system architectures

The performance of the reference system concept against the future target set comprising fixed wing, helicopters, UAV, TASM, cruise missiles will vary considerably with target class, profile, signature. Although the autonomous building block provides a good fundamental capability against elements of the threat stream, it has inevitable limitations of robustness within the complete operational environment discussed previously. A broad appreciation of limitations is:

- the radar emission signature may be unacceptable in Zone 1 applications;
- the radar will suffer terrain masking problems against very low level targets and has no capability against NLOS helicopters;
- the radar will be limited in range performance against highly stealthed targets within the full search volume;
- the combination of low and high level target profiles with low observable targets provides problems for MFR resource management;
- overall situational awareness will be poor, and, in particular, air target classification and identification is likely to be far from robust enough to permit autonomous engagement decisions in difficult operational environments;
- although the missile with multi-spectral seeker provides a cost - effective kill mechanism against manned platforms and missile targets, engagements against relatively cheap targets raise concerns.

The critical limitations apply to surveillance and identification prior to missile launch. SCI032 took the approach of considering two broad categories of multi-sensor and sensor fusion enhancement to these aspects of the reference system functionality. These are:

- the addition of collocated, complementary sensors to the MFR;
- embedding the reference system in a distributed sensor architecture.

Reference system with multiple collocated sensors

The following multi-sensor concepts have been proposed to fill the perceived capability gaps of the reference system by introducing:

- a passive sensor suite to provide covert surveillance, cueing, and fusion with radar plot and identification data;
- a low frequency radar to provide a capability against low (conventional radar) observables, surveillance cover against high altitude targets, and, to use this information to cue primary surveillance for efficient management of the scanned aperture;
- a sensor suite which can provide detection, location and identification of masked helicopters;
- a laser sensor damage adjunct to provide an alternative target defeat mechanism.

The reference system with multiple sensor options and DET adjunct is illustrated in Figure 9. This postulates, for NLOS target acquisition, concurrent airborne and ground-based sensor options although cost considerations, *inter alia*, might dictate choice of a single module. In addition, the cost and operational implications of a dedicated low frequency radar are likely to preclude use on a one-on-one basis. In this respect it may be more appropriate to consider distributed, shared operation of such a facility on the basis of a wider, combined local air picture (LAP).

Figure 9 is intended to illustrate a functionally enhanced autonomous building block with a framework of modularity. A number of possibilities exist for complementary passive surveillance including IRST with spatial and temporal-based NCTR modes, and there is significant effort being expended in NATO nations on plot and track level fusion of IR and radar outputs. NLOS detection and identification techniques could incorporate, for example, sensors in tethered and UAV platforms, ground-based directional acoustic arrays and laser doppler velocimetry.

Integrated distributed system architectures

Although the concepts illustrated in Figure 9 offer the promise of a robust, autonomous capability against the wide threat stream, further enhancement can be postulated by pooling air target track and identification data from other organic surveillance units and from other sources originating from other Commands.

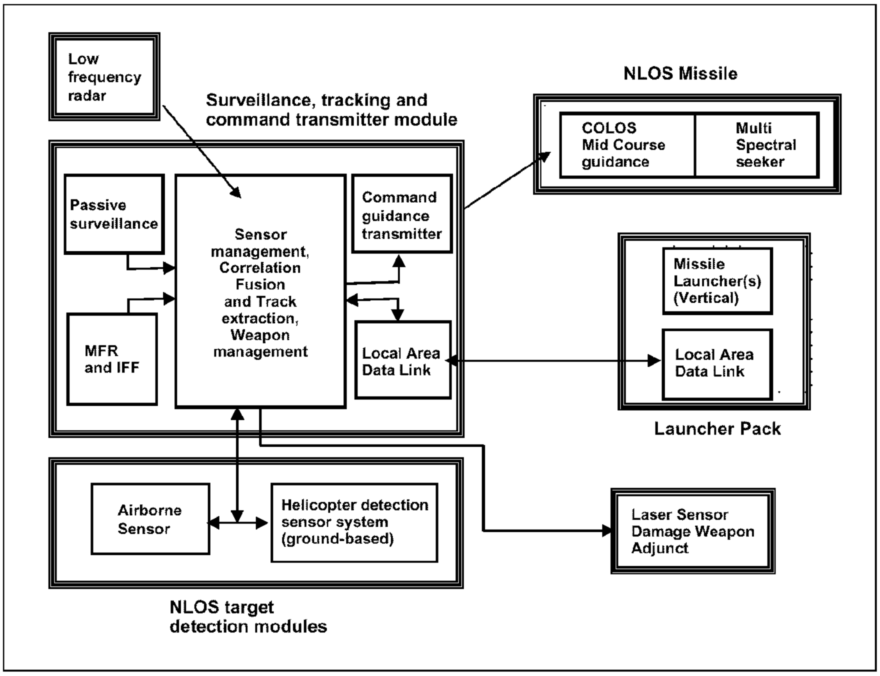

Figure 9: Multiple collocated sensors, DET adjunct

The principles at issue are the widest possible Situational Awareness and interoperability in a Joint environment.

These considerations lead to the concept of embedding configured, modular building blocks exemplified by Figure 9 in a distributed architecture with links to additional sources of air picture data. This is illustrated in Figure 10, which, although is not meant to imply a particular C3I architecture, introduces the concept of a picture compilation and weapon assignment node. The node is postulated as a focal point for fusing external data from other nodes and from sources such as Recognised Air Picture (RAP) and ISTAR platforms / ground stations distributed over wide area data links.

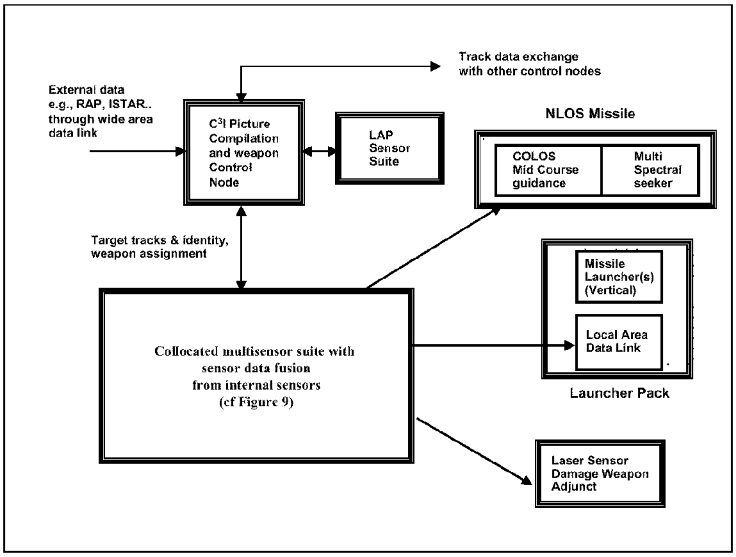

Figure 10: Integrated distributed system

Qualitative assessment of architectures

Phase 1 of the SCI032 work completed with a qualitative assessment of the benefits of moving through the concepts illustrated by Figures 8 to 10. The assessment is condensed into a Performance Improvement Matrix where a number of performance categories are examined in relation to a particular air target class and assessed on a three point scale from "poor" (P) through "good" (G) to "very good" (VG). The results are shown in Table 9 overleaf where each element of the matrix is divided into three cells with the first cell applying to the reference system, the second to local sensor fusion, and the third to a complete system of local and wide area fusion. Cells containing a cross denote no applicability/capability.

The major points arising from the reference system scoring are:

- the missile, based on a multi-spectral seeker, is very capable against small, highly manoeuvring targets, and has an NLOS capability against fully-masked targets, providing it can be cued by the surveillance system;
- the surveillance building block, the MFR, has good performance against fixed wing targets but is limited against helicopters and provides no capability when these targets are fully masked;
- the MFR is limited in provision of timely update data over the required large surveillance volume forced by all threat trajectories, and this is compounded by the most stressing threats being masked by terrain for at least part of the detection / track initiation / track maintenance process;
- whereas some target classification / recognition capability can be incorporated in the MFR using NCTR techniques, and IFF can be integrated, the overall capability for high integrity identification data is limited.

Scoring of schemes using multiple collocated sensors reflects greater robustness across the threat stream. In particular, the addition of NLOS helicopter sensors and a low frequency radar fill in significant gaps in MFR performance capability. The addition of passive surveillance sensors provides for covertness where scenarios dictate such a need. Fusion of spatial and identification data across the active and passive sensor suite promises the establishment of a Local Air Picture with enhanced integrity.

Finally, the scoring of combined local and wide area sensor and C^3I data, in a fully distributed architecture, reflects the goals of widest possible Situational Awareness and interoperability. The scoring assumes that future communications and processing technology will enable these goals to be achieved.

Modularity and operational flexibility

With that proviso, it is possible to iterate the modular reference system to provide a fair-weather Zone 1 variant. This uses the information provided by the sensor net to create the conditions mandated at the operational level for successful engagement.

Function	THREAT	Fixed wing	Helicopter		Cruise missile		TASM		UAV	
	SCENARIO	Combat support	Transit (LOS)	Attack (NLOS)	High altitude terminal dive	Very low altitude	High altitude terminal dive	Low altitude	Recce	Attack
Surveillance and ID										
Detection		G VG VG	P G VG	X P VG	P VG VG	G VG VG	P VG VG	G VG VG	P G VG	G VG VG
Track initiation		G VG VG	P G VG	X P VG	P VG VG	P VG VG	P VG VG	P VG VG	P G VG	P VG VG
Kinematics										
Position		G VG VG	P VG VG	X P VG	P VG VG	G VG VG	G VG VG	G VG VG	P VG VG	G VG VG
Identification										
Classification		P VG VG	P G VG	X G VG	P VG VG	G VG VG	P VG VG	G VG VG	P VG VG	G VG VG
Recognition		P VG VG	P G G	X G VG	X X X	X X X	P G G	P G G	P VG VG	P G G
Allegiance		P G VG	P G VG	X G VG	X X X	X X X	X X X	X X X	P VG VG	P VG VG
Situation assessment		G VG VG	P G VG	X P VG	P VG VG	P VG VG	P VG VG	P VG VG	P G VG	P VG VG
Threat assessment		P G VG	P G VG	X P VG	P VG VG	G VG VG	P G G	P G G	P G VG	P G VG
Weapon assessment		X X G	X X G	X X G	X X G	X X G	X X G	X X G	X X G	X X G
Threat engagement		G VG VG	G VG VG	X P VG	P VG VG	G VG VG	P VG VG	P VG VG	P G VG	P G VG
Kill assessment		P G VG	P G VG	X P VG	P VG VG	P G VG	P VG VG	P G VG	P G VG	P G VG

Table 9: Performance improvement matrix

Similarly, if the concept is considered to be a distributed modular system *ab initio*, a number of possible quasi-autonomous variants, based on specific operational requirements, become possible. The advantage is that this may be achieved without the need to create specialised fully-integrated vehicular systems. The important characteristic in this case is to be able to match or exceed the manoeuvre capability of the supported forces. An example might be a fair- or all-weather Zone 1 fire unit mounted on an armoured chassis for a particular type of operation, and a similar set of modules reconfigured onto a number of highly-mobile all-terrain platforms for another.

A modular distributed system would also allow the development of additional concepts. For example, it may be necessary to be able to deploy into sites which are inaccessible to anything other than troops on foot, especially where helicopter support is not forthcoming. In this case, a man- or crew-portable target engagement element, which could access the full latent power of the distributed system, might provide an elegant, and effective, solution.

A concept of operations (CONOPS) for a distributed modular system in the future timeframe has been developed in support of the concept described. Analysis has confirmed the substantial performance advantages, as well the more obvious benefits in tactical and operational terms. Sensors which can be elevated sufficiently to operate clear of close screening can be shown to provide the most flexibility, security and survivability in system terms. This effect is most marked, perhaps unsurprisingly, in Zone 1. Given the combination of advantages conferred by the concept – the deployability and high engagement rate conferred by a multiple vertical-launch missile pack, and near-circular coverage in the end-game conferred by capable high-speed homing missiles - the weapon system becomes broadly only limited by the capabilities of the sensor net and the timeliness and bandwidth of the communications system.

Separation of the weapon element from the sensor element allows both to be optimized separately. This has major tactical advantages over collocated systems in the defence of mobile operations, as sensor siting and movement are not hamstrung by the demands of conventional mutual support. Similarly, as long as it remains

within useable sensor coverage, the centre of the weapon system footprint may be placed where it is really wanted – to defend the target – even to the extent of being sited amongst the forward troops. Operational benefits in terms of robustness, survivablity and capability against the most stressing threats may also be seen reflected in Zone 2 deployments.

In information dominance terms, the concept, as outlined, fits more closely the developing doctrine. For crisis reaction forces, the emphasis on sensor networks allows greater flexibility in planning and employment in non-warfighting situations without compromising the ability to match any subsequent escalation. It is also not difficult to envisage the advantages of distributed systems in such conditions as peace support deployments for isolated enclaves, especially as the weapon element may be kept non-provocatively covert and passive, up to the moment of engagement.

Within the basic principles of war, which have not substantially changed since Sun Tzu's time, distributed modular systems would allow many of the conventional employment and deployment rules to be re-written. This concept would help provide a broadly effective answer to what has hitherto always been, and increasingly will become, a series of intractable problems for the AD of ground forces.

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